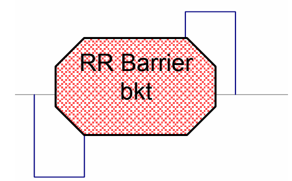
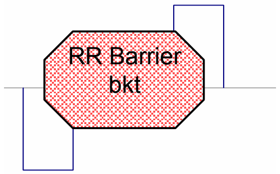



# Longitudinal Beam Tomography by Monte Carlo Method

Chandra Bhat

RR Group Meeting
September 26, 2007



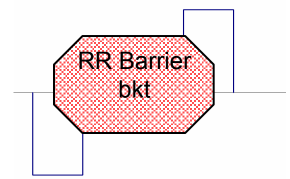

# Motivation

- Get realistic longitudinal phase space distribution of the beam particles in an arbitrary rf bucket in a circular accelerator/storage ring
- Extract longitudinal emittance

# Monte-Carlo Beam Longitudinal Tomography

- Used Monte-Carlo technique to make longitudinal tomography of Recycler Beam ← the technique is quite standard in HEP data analysis and in other fields .
- Inputs:
  - Machine parameters
  - RF wave forms
- Data to compare with
  - RWM (Recycler Wall Current Monitor data) Generally this should be sufficient to get the tomography (Alexey Burov)
  - Recycler Schottky data (Longitudinal Spectra: ungated and gated)
- Equations of motion in ($\Delta E$, $\Delta t$ )-phase space

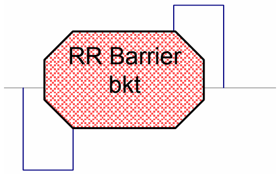
$$\frac{d\tau}{dt} = -\eta \frac{2\pi \, \Delta E}{T_0 \beta^2 E_0} \quad \text{and} \quad \frac{d(\Delta E)}{dt} = \frac{eV(\tau)}{T_0}$$



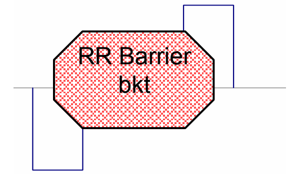

# Monte-Carlo Beam Longitudinal Tomography

- Random Population of the beam particles in ($\Delta E, \Delta t$)-phase space← This is where the Monte Carlo nature of the problem solving enters in the whole enterprise
  - ❑ Use Schottky and RWM data to guide you to decide what type of initial distribution to use and get final beam tomography.
- How one gets beam Tomography
  - ❑ Start with single-particle beam dynamics
  - ❑ Model other collective effects if they are important
    - ➢ space charge effects ⇐
    - ➢ Broad band impedances ⇐
    - ➢ Beam loading effects
    - ➢ Cavity phase and voltage modulation effects ← not used in the current case
    - ➢ etc.
- This is a simple minded and straight forward technique with lots of patience.
- This work started in 2002
  - ❑ C. M. Bhat and J. Marriner, PAC2003, (2003) page 514.

# Monte-Carlo Beam Longitudinal Tomography



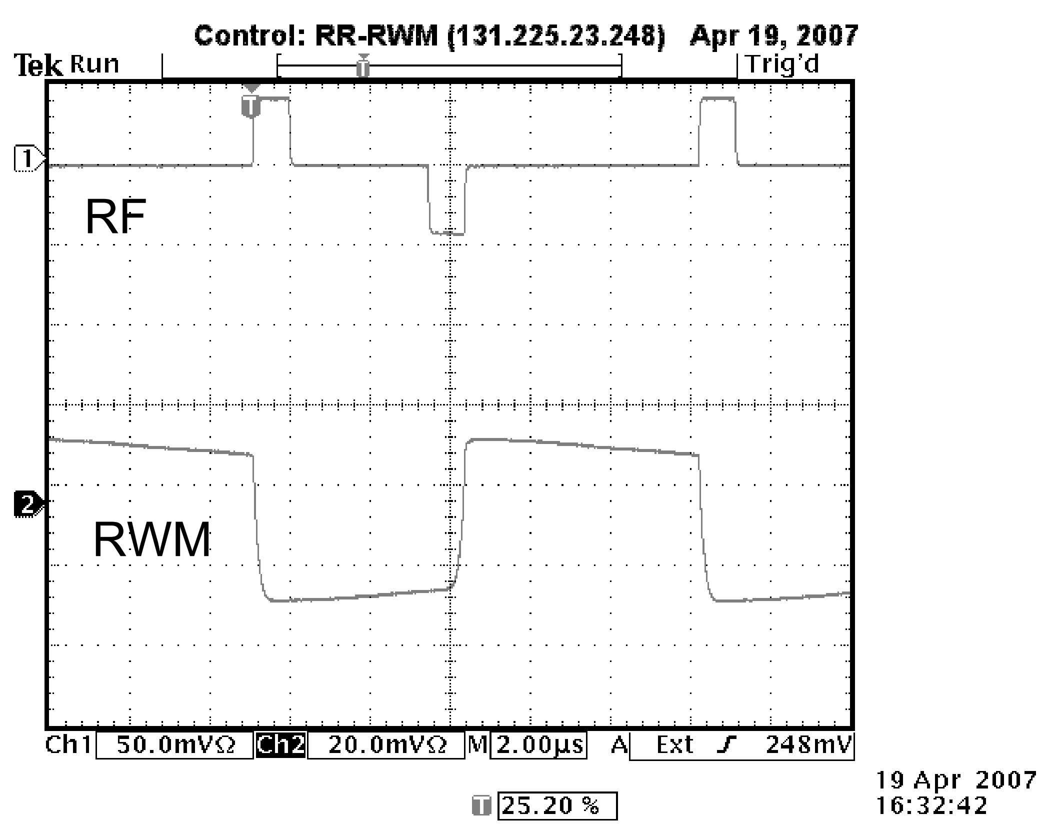

- Used two different 2D-programs
  - Developed a simple computer program that uses the equations of motion (Bill Ng, original program). Modified it to incorporate e-cool and stochastic cooling (thanks to Dan, Lionel and Sasha).
  - ESME ← All the results in today's presentation are based upon the ESME simulations.
    - Current: Used measured data to construct the ($\Delta E, \Delta t$)-phase space distribution of the particles.
    - Past: Start with a ideal distribution and ideal rf waveform. Follow the evolution of the phase-space distributions and learn about beam dynamics.
- What we need is, a 6D program to get complete tomography of the beam.

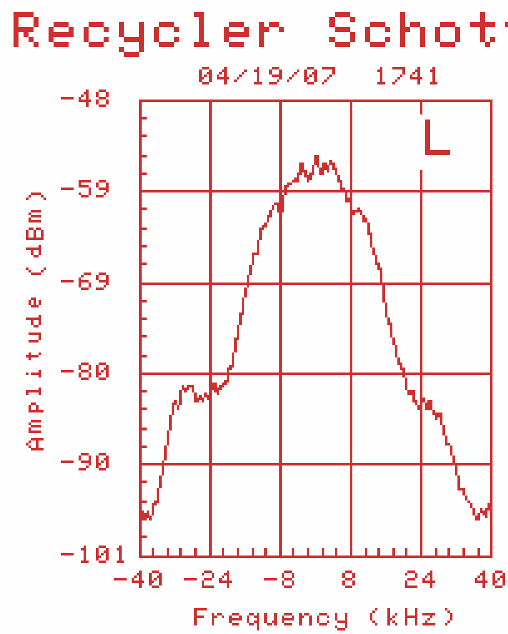



# Examples

- Beam in a standard "Cold barrier bucket"
- Beam in "Compound bucket"
- Case of "Phase-space Coating"

# 122E10 pbars in Cold Barrier Bucket




F_rev=89811.242 Hz
Intens= 12.795 E11
Dp(sig)= 3.5954 MeV/c
Dp(90%)=12.0243 MeV/c
emitl1(95%)= 86.3760 eV·
Tsep1= 5.8513 usec
H_tune= 0.4455
H_emit= 6.224 p-mm-mrad
V_tune= 0.4491
V_emit= 5.993 p-mm-mrad
Beam =12.157 E11
n_avg = 64

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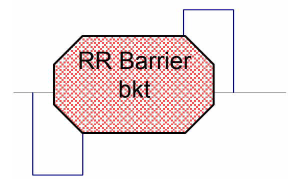
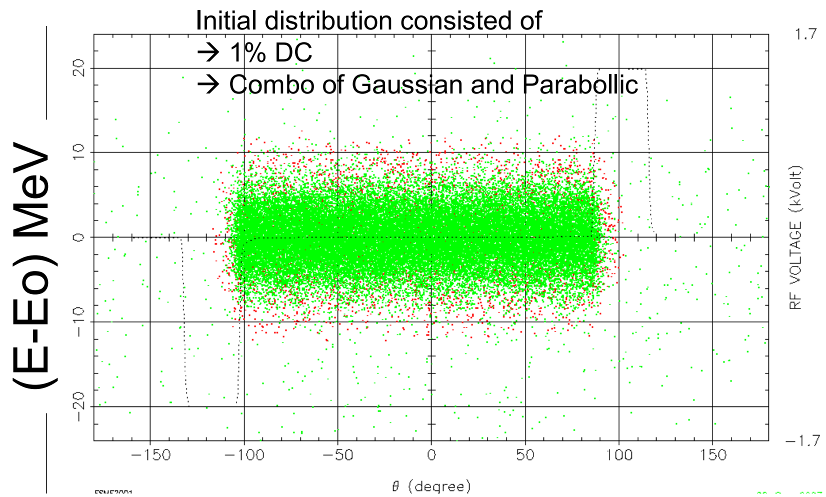
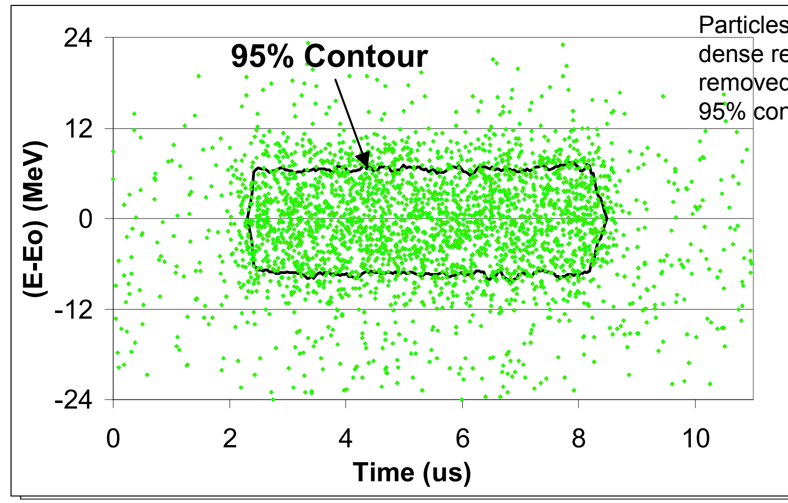
RR Barrier bkt

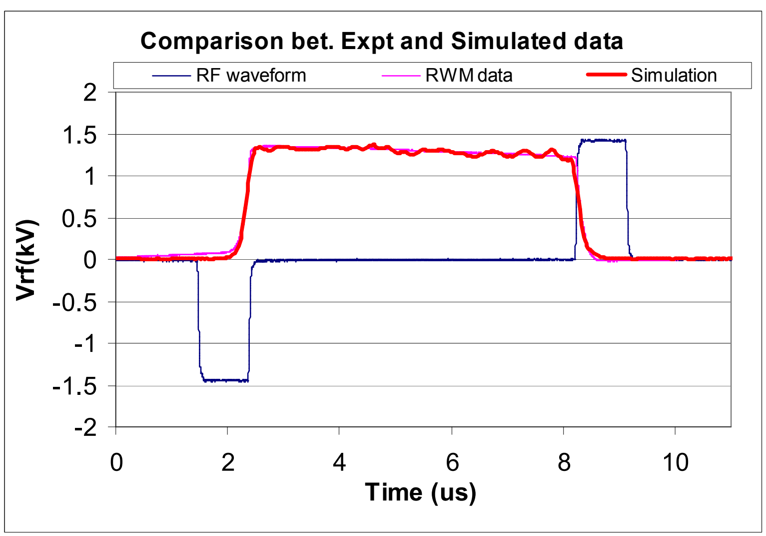
# 122E10 pbars in Cold Barrier Bucket (cont.)



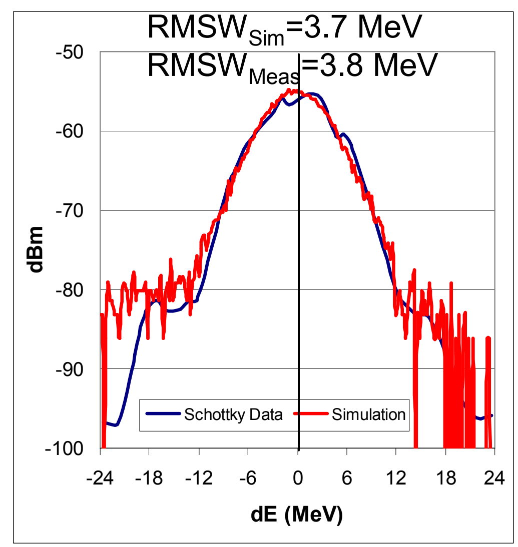




Particles from the dense region are removed to make 95% contour visible.




Current:
LE(95%) = 82.9 eVs

R37:
LE(95%) = 86.4 eVs

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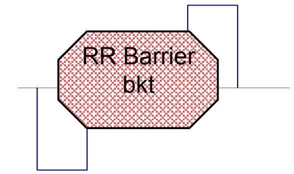
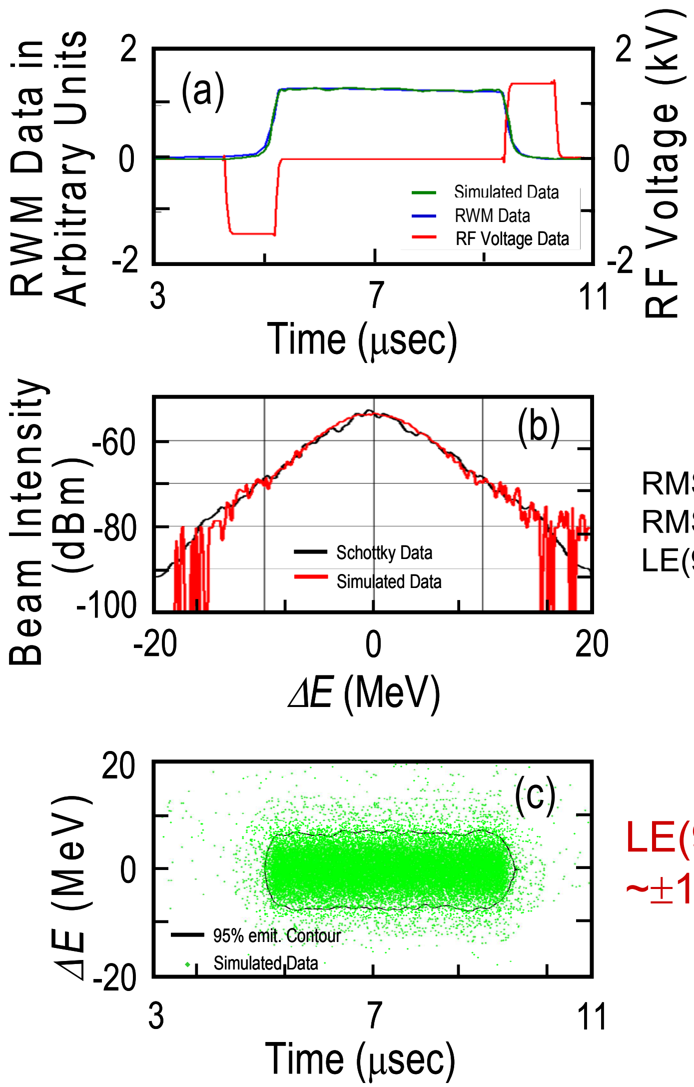
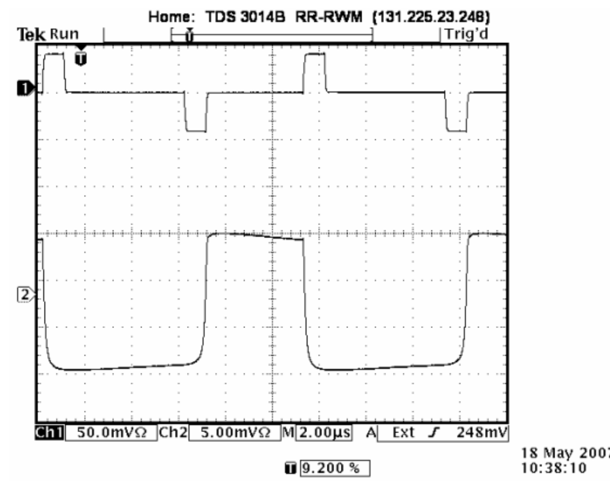
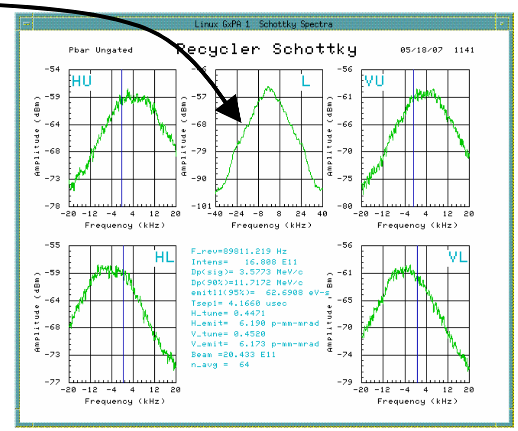
# 204E10 pbar "Cold Beam"




RMSW$_{Expt}$=3.67 MeV
RMSW$_{Sim}$=3.67 MeV
LE(95%) = 62 eVs




204E10 pbars
RMSW$_{Expt}$=3.58 MeV
LE=62.7 eVs

LE(95%)= 62 eVs
~±10% error

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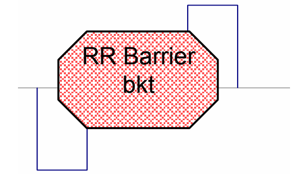
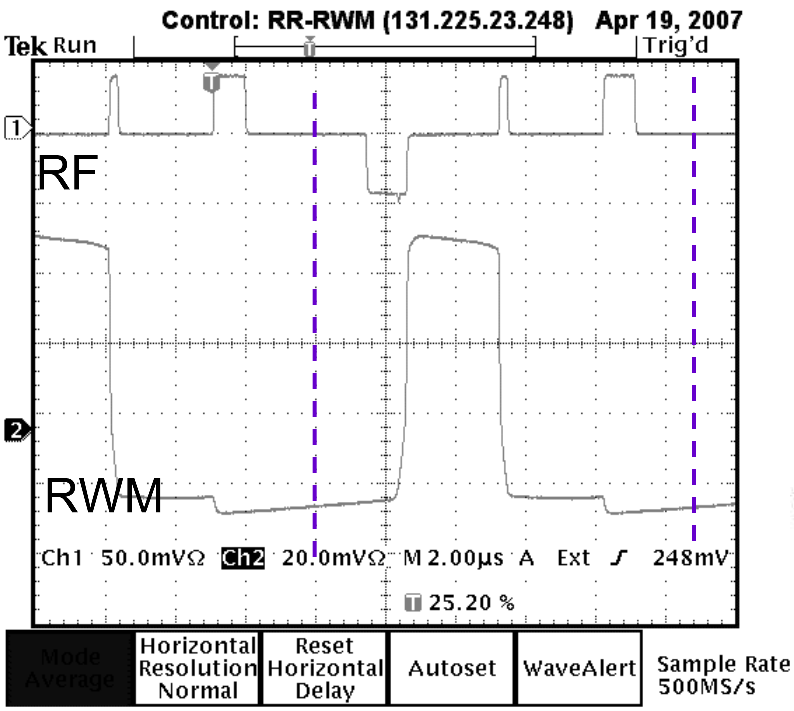
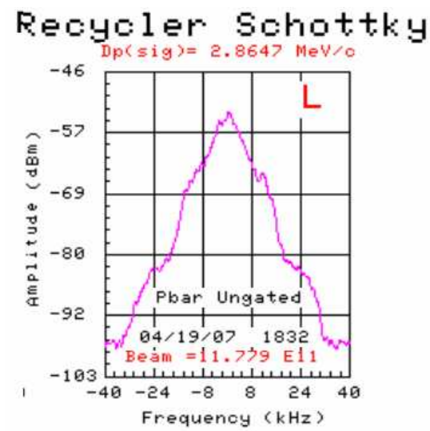


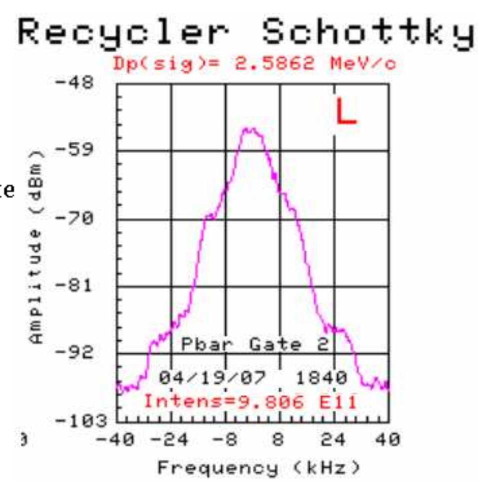

# Compound Bucket

Beam= 122E10 pbars

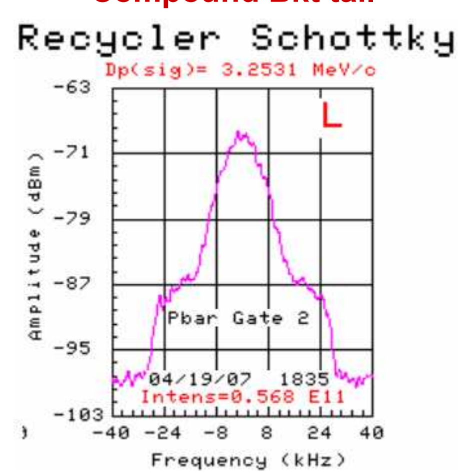



Compound Bkt Core




Compound Bkt tail

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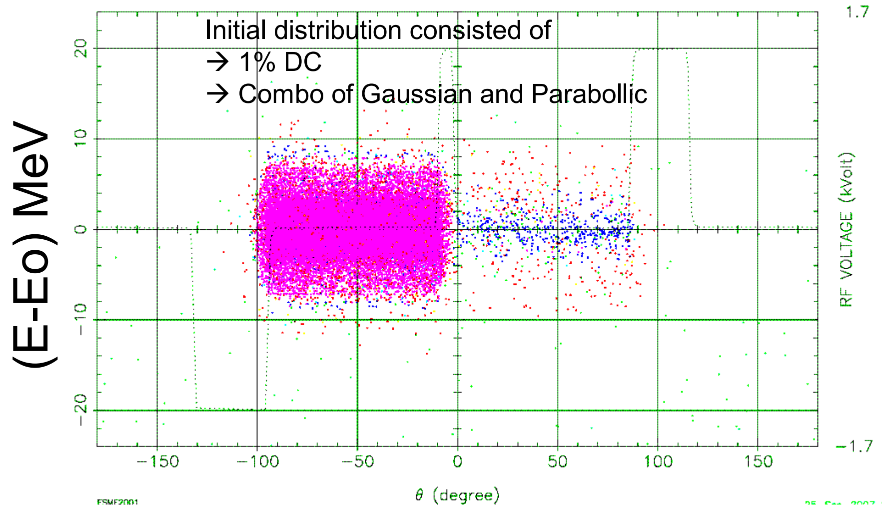
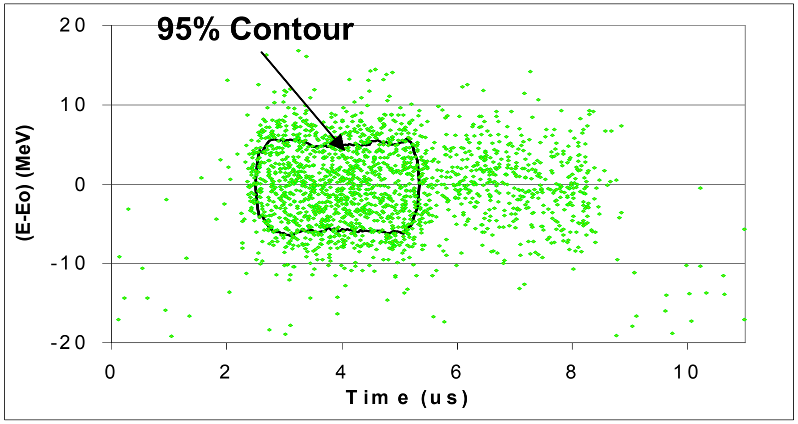
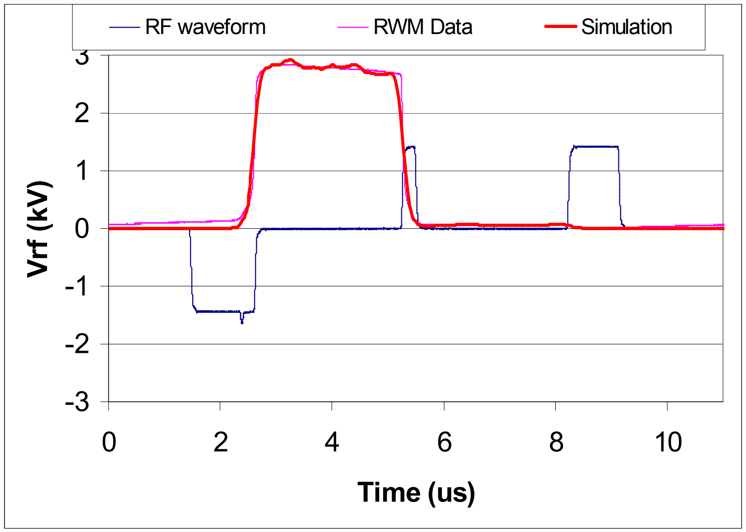
# 122E10 pbars Compound Bucket (cont.)



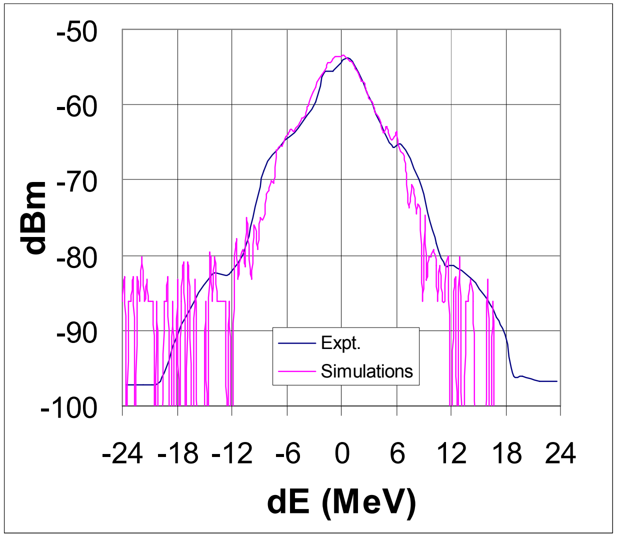



RMSW$_{Sim}$=2.7 MeV
RMSW$_{Meas}$=2.9 MeV




Current:
LE(95%) = 30.2 eVs

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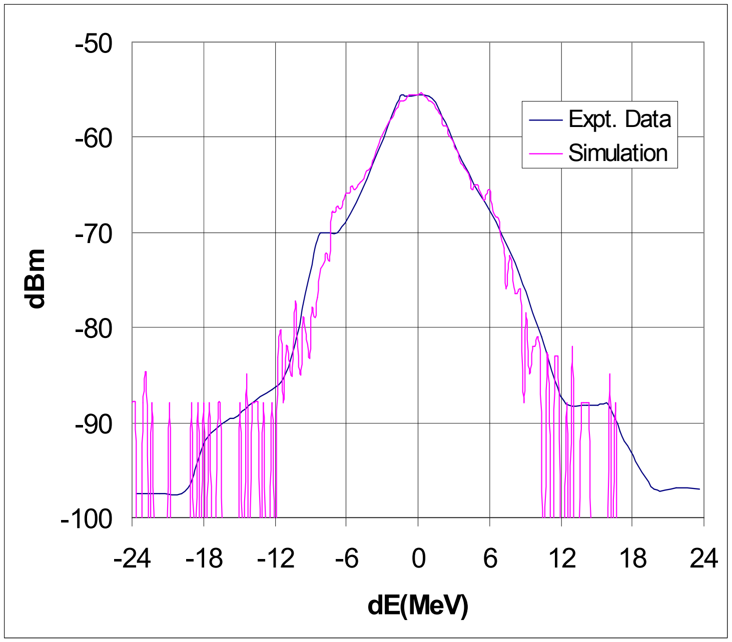
# 122E10 pbars Compound Bucket (cont.)

RR Barrier bkt

## Core

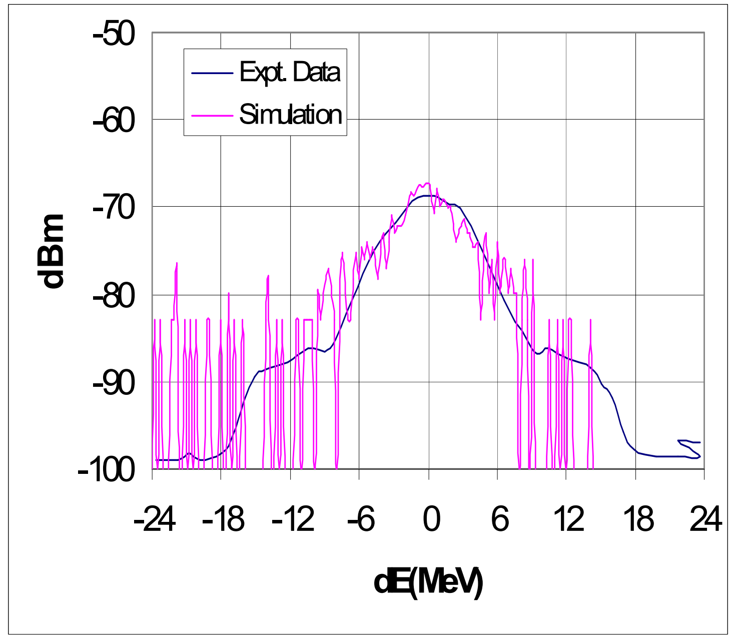
$RMSW_{Sim}$=2.62 MeV
$RMSW_{Meas}$=2.45 MeV




Current:
LE(95%) = 30.2 eVs

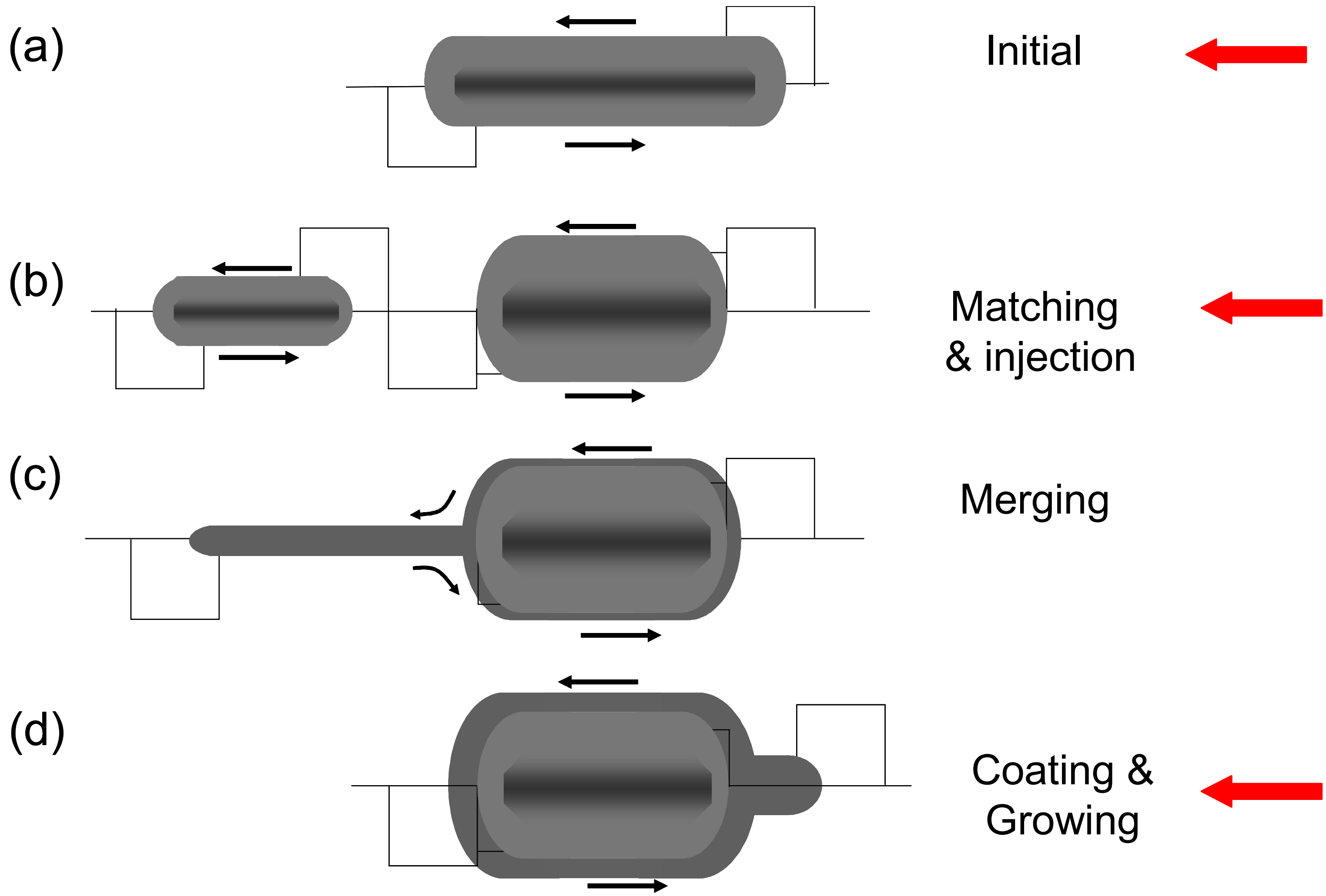
## Tail

$RMSW_{Sim}$=4.8 MeV
$RMSW_{Meas}$=3.5 MeV



# Longitudinal Phase space Coating

RR Barrier bkt

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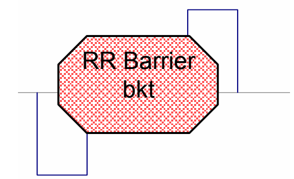
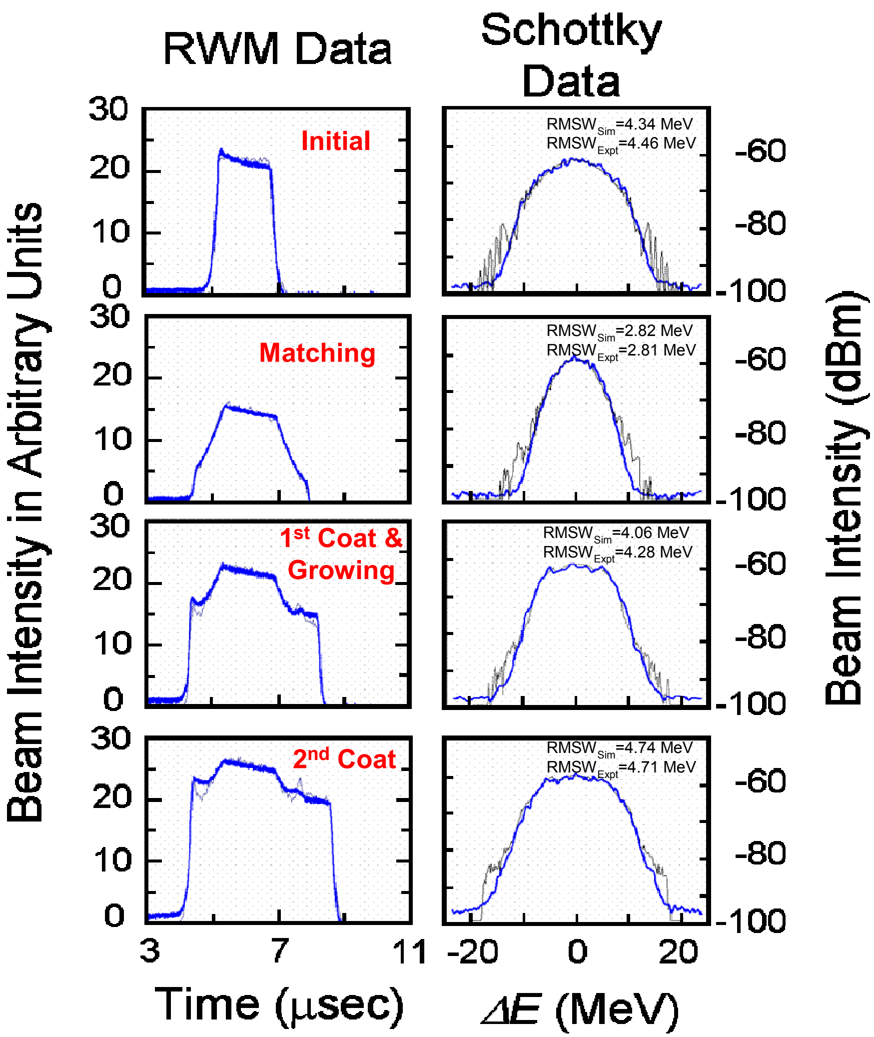
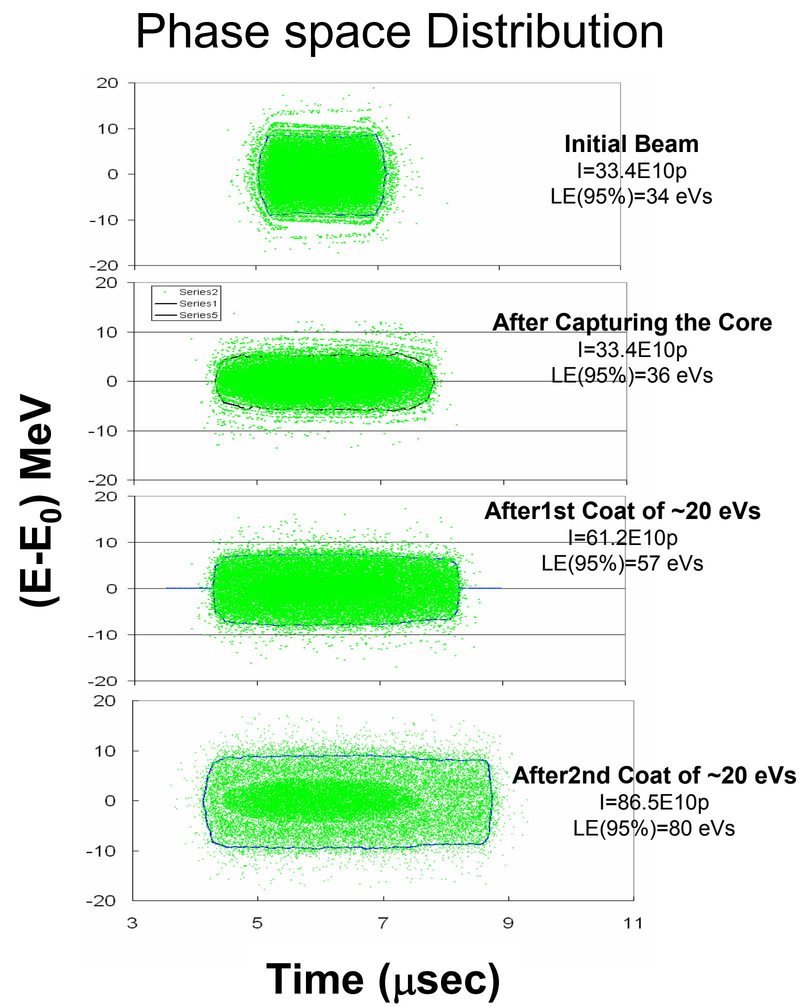
# Longitudinal Phase space Coating Protons




(Simulations with space Charge effects)

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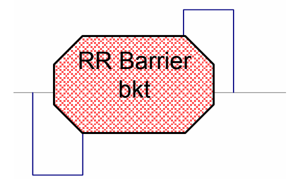
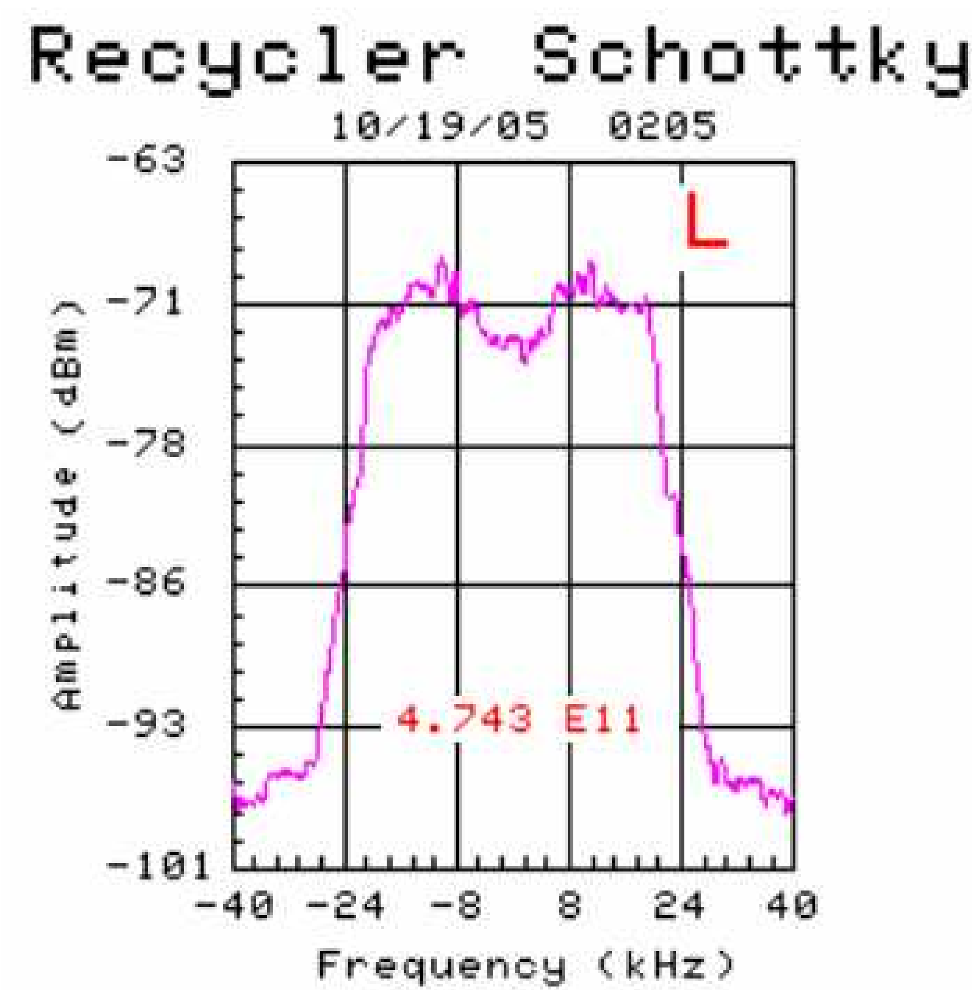
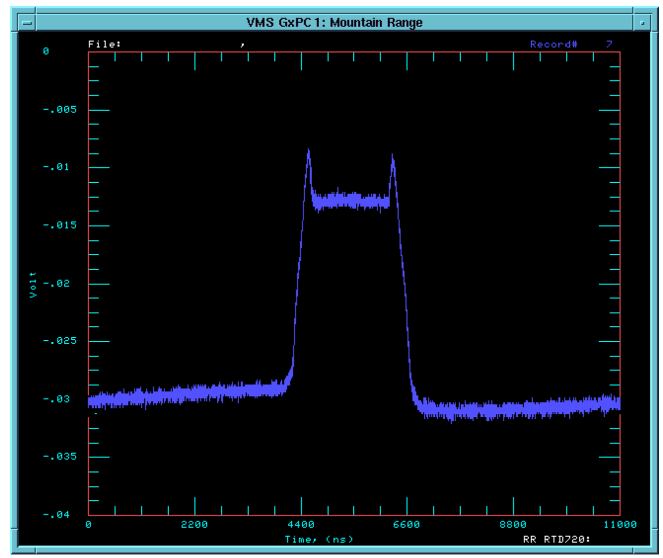
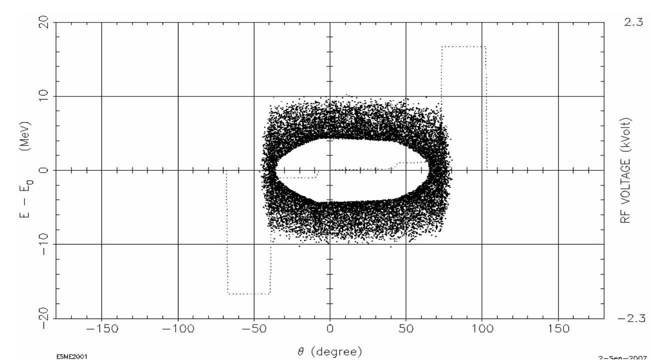



# Hollow Beam
## (work in Progress)

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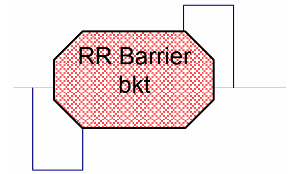


# Pros & Cons and Issues

- This method (in principle) gives accurate representation of the phase-space distribution of the beam in an RF bucket, i.e., Beam Tomography. Hence, one can estimate emittance quite accurately.
- Issues:
  - Statistics versus computation time
  - What is 95% longitudinal emittance for a compound bucket or for a more complex bucket. Notice that at 600E10 about 30 E10 beam will be outside the 95% region